Natural vegetation recovery on waste dump in opencast coalmine area

CHENG Jian-long, LU Zhao-hua*
Institute of Restoration Ecology, China University of Mining and Technology, Beijing 100083, P. R. China

Abstract: The changes of vegetation compositions, plant species diversity, species important value and succession of plant community were studied on waste dumps in Haizhou opencast coalmine which is located in the west of Liaoning Province, China (41°41′–42°56′ N, 121°1′–122°56′E). Four kinds of terraces with different ages (5, 10, 20 and 40 years) were selected for investigation of plants. Total of 63 species of natural colonized plants were recorded on the waste dump and they belong to 23 families. The main families were Compositae (15 species), Fabaceae (11 species) and Leguminosae (8 species), which accounted for 54.0% of total species and play an important role in natural vegetation recovery in waste dump area. The dominant species on 5-, 10-, 20-, 40-year-old terraces were *Tribulus terrestris + Echinochloa hispidula + Salsola collina, Echinochloa hispidula + Artemisia sieversiana + Artemisia scoparia, Echinochloa hispidula + Clinelymus dahuricus + Artemisia scoparia + Artemisia sieversiana + Melilotus officinalis, Clinelymus dahuricus+Phragmites communis + Echinochloa hispidula+ Setaria viridis*, respectively. According to the important value of species calculated. It is determined that *Tribulus terrestris* can act as pioneer species on waste dump and *Clinelymus dahuricus, Phragmites communis* and *Echinochloah hispidula* are important dominant species in vegetation restoration in Haizhou opencast coalmine. The study results can provide scientific basis for selecting and disposing appropriately plant species and rehabilitating vegetation on waste dumps of coalmine.

Key words: Haizhou; Opencast coalmine; Waste dump; Plant community; Restoration
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Introduction

In opencast working, surface earth and underground rock is peeled off and piled on the earth's surface. It is reported that waste dumps (which have held land about 1400 hm^2 until 1994) in China occupy land about 0.16 hm^2 land area per ten thousand tons coal production (Gao *et al.* 1999). In addition, they contaminate soil, air and water, increase loss of water and soil in mine area and put great pressures on vulnerable ecological environment (Safaya, 1979; Fan 2003; Bradshaw 1997; Xiao 2001). Therefore, one of the significant tasks in ecological management in opencast mine is to restore and rehabilitate vegetation on waste dump. With waste dump of Haizhou opencast coalmine as experimental object, we studied species composition, changes of species diversity and succession of plant community in order to provide scientific suggestions for ecological restoration on waste dump in coalmine area.

Study area

Fuxin city is located in the west of Liaoning Province (41°41′–42°56′ N, 121°1′–122°56′ E). The study area belongs to the continental monsoon climate of the north temperate zone, with an annual mean temperature of 7.6 °C, annual mean precipitation 480mm and annual evaporation 1746mm. The Haizhou opencast coalmine lies in south suburb of Fuxin city, occupying an area of 30 km^2 (include open-pit, industrial square, waste dump etc.), and waste dump and gangue dump is about 14.8 km^2.

Methods

Terrace age reduces from ground floor to the top in waste dump, thus vegetation on different terraces can be thought to be in different succession sequence. Selecting 5, 10, 20, 40 year-old terraces, the author wrote down all plant species and knew vegetation characteristics in each terrace, then selected representative vegetation type to sample. Plant species, abundance, height and coverage were surveyed in five 1m×1m sample plots established in every type. Plant species diversity and evenness were calculated with Shannon-Weiner index and Pielous index, respectively. Important value of each species was calculated according to Xu *et al.* (2003).

Results and discussion

Vegetation composition in different age terraces

There were 63 species of natural colonized plants belonging to 23 families on the waste dump in Haizhou opencast coalmine (Table 1). The main families were *Compositae* (15 species), *Fabaceae* (11 species) and *Leguminosae* (8 species), which accounted for 54.0% of total species. It indicated that these three families occupied important position in flora and played an important role in natural vegetation recovery on waste dump. In addition, there were Labiatae (4 species), Convolvulaceae (2 species), Chenopodiaceae (2 species), Polygonaceae (2 species), Plantaginaceae (2 species), Asclepiadaceae (2 species) and Solanaceae (2 species), Moraceae (1 species), Geramoaceae (1 species), Cruciferae (1 species), Roaceae (1 species), Umbelliferae (1 species), Tamaricaceae (1 species), Zygophyllaceae (1 species), Amaranthaceae (1 species), Ulmaceae (1 species), Elaeagnaceae (1 species), Portulacaceae (1 species), Urticaceae (1 species) and Iridaceae (1 species). Among all plant species, annual and biennial accounted for 37 species; perennial plants accounted for 26 species including 7 woody plants.

Plant species increased obviously along with terrace age, which meant that community structure became more complicated.

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Biography: CHENG Jian-long (1976~), male, Ph. Doctor in Institute of Restoration Ecology, China University of Mining and Technology, Beijing 100083, P.R. China
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*Author for correspondence, E-mail: lu-zhh@263.net

The proportion of perennial species was 23.5%, 35.5%, 37.5% and 43.8% at the terraces with age of 5, 10, 20, and 40, respectively. Community including high proportional perennial plants is commonly more steady than annual or biennial community. Reason of forming this sequence might be as follows. Surface substance on waste dump, which was from several dozen meters deep under the earth's surface, was unfavorable for plants to grow or survive. Under such abominable condition, annual had high conspicuousness according to reproductive patterns theory. The fertility of these lean soils increased gradually under biotic and abiotic factors along with terrace age and more natural plant species can colonize on terraces, therefore, perennial plants can colonized and propagate because of high competitive ability in the circumstances.

Table 1 Plant composition in different age terraces

Age of terraces	Family	Species	Perennial plant	Shannon diversity	Pielous evenness	Species of three families			
						Compositae	*Leguminosae*	*Fabaceae*	Sum
5	13	17	4	0.97	0.24	2	3	0	5
10	10	31	11	1.45	0.29	8	7	4	19
20	19	40	15	1.97	0.37	8	5	7	20
40	17	48	21	1.51	0.27	12	8	8	28
Total	23	63	37			15	8	11	34

Vegetation on a series of terraces represented deferent succession sequence. On 5 year-old terrace there were 17 plant species including 4 perennial plants, and the dominant species were short, drought-enduring annuals such as *Tribulus terrestris* and *Salsola collina*. The community had high instability, because vegetation coverage changed greatly in years or seasons, for instance, *Salsola collina* can formed thick groupings in moist years but greatly reduced in drought years. On 10 year-old terrace there were 31 species including 11 perennial plants. The proportion of three big families increased from 29.4% to 61.3%. Total of 40 species including 15 perennial plants were found on 20 year-old terrace. *Echinochloa hispidula, Clinelymus dahuricus, Artemisia scoparia, Artemisia sieversiana* and *Melilotus officinalis* were dominant species on 20 year-old terrace, but *Tribulus terrestris* became rare species. *Fabaceae*, which is generally difficult to become dominant species, turned into constructive species. It might be because the dominant species in community was not obvious in this succession stage and the community structure was unstable. *Fabaceae* can enhance soil fertility through fixing nitrogen from air, which will improve soil environment and speed up succession of plant community. Forty eight species including 21 perennial plants were recorded on 40 year-old terrace. Perennial plants, *Clinelymus dahuricus* and *Phragmites communis*, became dominant species. The species number belonging to *Compositae, Fabacea,* and *Leguminosae* is 12, 8, and 8 respectively..

Changes of important value of dominant species

Important value (IV) can show relative possession of ecological resources and functional status in community. High IV means big competitive power and high utilization of resources. IV of *Tribulus terrestris* was much higher than other species on 5 year-old terrace, and its conspicuousness was extremely outstanding but low on other terraces (Table 2). It indicated that *Tribulus terrestris*, acting as pioneer species, could improve rapidly vegetation coverage in ecological restoration. IVs of *Artemisia sieversiana* and *Artemisia scoparia* increased firstly and got to maximum on 10 year-old terrace, then began to decrease. They completed the period of invasion, spread, dominance, and contabescence in 40 years. *Echinochloa hispidula*, as obstinate weed, always kept high conspicuousness among different age terraces, and its slowly decreasing IV indicated that *Echinochloa hispidula* contributed to keeping community stability. IVs of *Clinelymus dahuricus* in terraces, which rose from 0.26 on 5 year-old terrace to 1.87 on 40 year-old terrace, showed that its functional status in community gradually increased in succession sequence. Finally, *Clinelymus dahuricus* turned into dominant species in 40 year-old terrace (Table 2).

Table 2 Important values (IV) of plant species in deferent age terraces

5 year-old terrace		10 year-old terrace		20 year-old terrace		40 year-old terrace	
Plant Species	IV	Plant Species	IV	Plant Species	IV	Plant Species	IV
Tribulus terrestris	2.81	*Echinochloa hispidula*	1.76	*Echinochloa hispidula*	1.56	*Clinelymus dahuricus*	1.87
Echinochloa hispidula	1.71	*Artemisia sieversiana*	1.57	*Clinelymus dahuricus*	1.55	*Phragmites communis*	1.27
Salsola collina	1.69	*Artemisia scoparia*	1.57	*Artemisia scoparia*	1.48	*Echinochloa hispidula*	1.00
Portulaca oleracea	0.77	*Clinelymus dahuricus*	1.04	*Artemisia sieversiana*	1.42	*Setaria viridis*	0.98
Clinelymus dahuricus	0.26	*Salsola collina*	0.90	*Melilotus officinalis*	1.41	*Artemisia scoparia*	0.84
Amaranthus retroflexus	0.13	*Setaria viridis*	0.78	*Lathyrus palustris*	0.97	*Kummerowia striata*	0.75
Setaria viridis	0.12	*Tribulus terrestris*	0.66	*Ulmaceae pumila*	0.95	*Ulmaceae pumila*	0.71
Avena sativa	0.06	*Xanthium sibiricum*	0.53	*Kochia scoparia*	0.93	*Amethystea caerulea*	0.62
		Melilotus officinalis	0.52	*Salsola collina*	0.86	*Artemisia sieversiana*	0.60
		Cynanchum thesioides	0.51	*Setaria viridis*	0.75	*Plantaginaceae depressa*	0.56
		Lathyrus palustris	0.34	*Kummerowia striata*	0.55	*Avena sativa*	0.47
		Avena sativa	0.34	*Centipeda minima*	0.51	*Cynanchum thesioides*	0.43
		Amethystea caerulea	0.29	*Amethystea caerulea*	0.51	*Melilotus officinalis*	0.32
		Kochia scoparia	0.25	*Avena sativa*	0.41	*Salsola collina*	0.28
		Centipeda minima	0.24	*Leibnitzia anandria*	0.34		

Liu (2003) found that *Echinochloa hispidula* and *Setaria viridis* belonged to gramineous ruderal with high potential for risk-sharing, and they had positive roles to the continuity of offspring in high disturbed environment. The common effects of

environmental factors on their seeds, such as soil moisture, thickness of soil and illumination in waste dump, increased survival probability of these two seedlings on barren soil, so *Echinochloa hispidula* and *Setaria viridis* played an important role in community succession on waste dump. According to summation of IV in four terraces, the order of dominant species was *Echinochloa hispidula* (6.03), *Clinelymus dahuricus* (4.72), *Artemisia scoparia* (3.89), *Artemisia sieversiana* (3.59), *Tribulus terrestris* (3.47), *Setaria viridis* (2.63), *Salsola collina* (1.69) and *Phragmites communis* (1.27). The IV could show the niche extent of species in succession process and act as indicator in species selection in ecological restoration.

Changes of species diversity and evenness

Shannon-Weiner and Pielous evenness indices increased rapidly and reached a maximum in 20 year-old terrace, after then decreased gradually (Table 1). Their trochoids were rising-peak-descending parabolas. The reason may be that community with several leanness-enduring or high diffusible pioneer species and low abundance in early restoration had low diversity and evenness. IV dispersions between dominant species and companion species decreased on 20 year-old terrace (Table 2), so ambiguity of dominant species made diversity and evenness high. On 40 year-old terrace, species diversity and evenness decreased synchronously and IV of dominant species went up significantly, which meant that the community developed in the direction of few dominant species.

Species diversity and community stability in ecological restoration

Stability and diversity are important and difficult issues in restoration ecology. Community stability includes resistance stability and resilience stability. The former is the ability that community resists disturbance and maintains systematic original structure and function, and the latter is the ability that community comes back after suffering disturbance (Ge 2002; Odum 1983). For a long period, many researchers explained community stability by species diversity (MacArthru 1955; Tilman *et al.* 1994), but the stability theory resulted from diversity could only explain some complex community. Huang *et al.* (1994); Li *et al.* (2003), Li *et al.* (2004), and Wang *et al.* (2003) have found that community with high stability did not always hold high diversity and the peak of diversity did not exist in climax community. Therefore, diversity is only a basic factor for community stability.

Climax community has high stability, because its high ache differentiation avoids direct competition between species, which slows down the succession speed and guarantees the inside stability of plant community, on the other hand, the community has high resilience stability and resistance stability to external disturbance. In practice, we always think over high diversity for stability against external disturbance, but neglect internal stability of plant community. For instance, the mode of *Agropyron cristatum* + *Astragalus assurgens* + *Hippophae rhamnoides* + *Robinia pseudoacacia* returned to an inferior and simple vegetation in ecological restoration experimentation in Antaibao opencast mine (Li 2000).

Conclusions

There are 63 species of natural colonized plants belonging to 23 families on the waste dump. The main families are *Compositae* (15 species), *Fabaceae* (11 species) and *Leguminosae* (8 species), which play an important role in natural vegetation recovery in waste dump.

Important value (IV) can show relative possession of ecological resources in community and act as indicator in species selection in ecological restoration. Being pioneer species, *Tribulus terrestris* can rapidly improve vegetation coverage on waste dump; *Clinelymus dahuricus, Phragmites communis* and *Echinochloa hispidula* are important dominant species in community succession.

It may take several decades or hundred years for vegetation on waste dump to reach the climax, so it is a significant way to restore vegetation in wasteland using engineering and biologic techniques (Li 1995; Ren 2001). The most important thing is to structure stable and sustainable ecosystem in ecological restoration, but the notion was wrong that using local species and adopting grass-shrub-arbor mode could design a stable community with high ecological benefits. Therefore, to enable artificial community to utilize environmental resources efficiently and to evolve steadily from simple to complicated, it is important to consider community biological characters and plant ecophysiological characters in vegetation restoration.

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